graphical location of the end point in spite of the distribution of observing stations; and as the path was nearly vertical there can be little more error in the location of the beginning point.

TABLE 2

Date: 1935 February 27, 6:20 p. m., eastern standard time.
Sidereal time at end point: 69°10'.
Ended over: λ=77°41', φ=+40°11'.
Height at beginning of train: 61.7±7.8 km.
Height at end of train: 31.1±3.3 km.
Length of path: 30.9 km.
Radiant (uncorrected): $\begin{cases} a=233° \\ h=82° \end{cases}$
Radiant (corrected): $\begin{cases} a=233° \\ h=81° \end{cases}$ $\begin{cases} a=79°.5 \\ \delta=+45°.7 \end{cases}$
Velocity of train drift (minimum) at 62 km: 121 km/hr.
Velocity of train drift (minimum) at 29 km: 79 km/hr.

The fireball itself was considerably brighter than Venus; and the duration of the train was certainly 12 minutes or more. Several drawings of the train were sent in, all showing most clearly that from a straight line at the beginning, almost vertical but sloping slightly from north to south (the angle as seen from due east was 85°), it gradually took the form of a zigzag line with two major projections, one at the top and one at the bottom. F. W. Smith at Glenolden, a trained meteor observer, plotted the train to scale on a star map, and our calculated velocities of drift depend on his drawing. The other reports were most useful in confirming the direction of the upper and lower drifts, and in very roughly confirming their values. Unfortunately, lacking any similar drawing made from a station more or less at right angles to his, we can deduce only the *projected* and therefore *minimum* drift. There is some reason to think, from a study of all the accounts and drawings,

that for this train the drift was actually to north or south, so that these minimum figures are approximately the true ones.

Smith's drawings, made with the aid of an opera glass, show three bulges to the north and three to the south; the approximate drifts, in order of decreasing altitude, are given in table 3. With allowance for inevitable errors of observation, it is clear that several superimposed currents were flowing in opposite directions, the most marked being at the top and bottom. These were clearly drawn by other observers, as well as by Smith.

The visible train was wholly below the limit of 75 km given by Trowbridge for long-enduring night trains; his theory for their long visibility would presumably not apply, and we are forced back upon reflection from dust or smoke as the more probable explanation. Calculations based upon the motions of the train give approximate wind velocities at several altitudes far above the earth's surface, altitudes in general too high to be reached by sounding balloons. The motions further illustrate the complexity and diversity in direction of these winds, and the danger of theorizing on the few data so far available.

The writer is greatly indebted to H. E. Hathaway of the U. S. Weather Bureau Office at Reading, Pa., for much help in obtaining several of the observations.

TABLE 3

Altitude	Velocity of drift	Direction of drift
km.	km/hr	
62	121	N. to S.
47	82	S. to N.
44	30	N. to S.
42	52	S. to N.
39	38	N. to S.
29	79	S. to N.

RELATION OF SEASONAL TEMPERATURES IN THE MISSOURI AND UPPER MISSISSIPPI VALLEYS TO ANTECEDENT PRESSURE DEPARTURES IN OTHER REGIONS

By T. A. BLAIR and A. G. TOPIL

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Although it is well known that pressure changes in various parts of the world are more or less closely related to subsequent weather changes in distant places, it is not possible in the present state of knowledge to say with certainty and without trial what widely-separated places will show a high degree of relationship. Hence, the work of finding such relations remains largely on an empirical, exploratory basis of trying out various combinations in the hope of finding some results of value, either for immediate application to forecasting or for the accumulation of data which, it may be hoped, will lead finally to some general interpretation of the interactions of the atmosphere.

During the winter of 1933–34 a large number of simple correlations of this character were calculated with funds provided by the Civil Works Administration, as has been reported by Weightman.[1] In one group of these, one element considered was the average temperature by seasons in the Missouri and upper Mississippi valleys, called district 5, computed from the records of 10 first-order Weather Bureau stations. The relations between these temperatures, and the pressures in some previous season at each of 69 stations distributed in all parts of the world, were determined separately. For the 4 seasons

there were 12 correlations for each pressure station, or a total of 828 correlation coefficients for the 69 stations. A number of these were large enough to indicate a definite connection between temperatures in district 5 and previous pressures elsewhere, but none were of sufficient magnitude to have any positive forecasting value. The largest was 0.679, connecting the spring temperatures in district 5 with the pressures at Midway Island during the preceding summer, 9 months earlier. In all there were 21 coefficients greater than 0.400.

The question naturally arises whether a better result can be obtained by using two or more stations, and considering their combined relation to the temperatures in district 5. A few such calculations, using two pressure stations, have been made, and the results are set out in table 1. The method of procedure was to select 2 of the 69 stations which showed important simple correlations with the temperatures of a given season, and to calculate from these total correlations the multiple correlation coefficients, using the formula,

$$R^2_1 = \frac{r^2_{12} - r^2_{13} - 2r_{12}r_{13}r_{23}}{l - r^2_{23}}.$$

In this equation the r's are the simple correlation coefficients that connect pairs of the values to be correlated,

[1] R. H. Weightman, Preliminary Report on Relationship between Temperatures in the United States and Precedent Pressures outside the United States; Transactions, American Geophysical Union, 15th Annual Meeting, April 1934, Part I, pages 12, 13.

indicated by the subscripts 1, 2, and 3; the subscript 1 indicates the temperature element.

In a few cases we have derived regression equations, and computed the departures of the temperature from normal on the basis of their relations to the pressure departures at the two distant stations. Table 2 contains one set of the observed and calculated values for each of the four seasons, and in figure 1 these values are compared graphically. Numerically, the degree of correlation between the observed and calculated values is expressed by the multiple correlation coefficient.

The regression equations take the simple form $x_1 = ax_2 - bx_3$, in which

$$a = \frac{(r_{12} - r_{13}r_{23})\sigma_1 x_2}{(l - r^2_{23})\sigma_2}$$

and

$$b = \frac{(r_{13} - r_{12}r_{23})\sigma_1 x_3}{(1 - r^2_{23})\sigma_3},$$

where σ is used for standard deviation. In order to get identical years of record for the three stations concerned in each multiple correlation, it was necessary to recalculate the simple correlations. Hence, the original C. W. A. computations have not been used in this paper except as a guide in the selection of the records to be correlated.

For the autumn temperature departures in the Missouri and upper Mississippi Valleys the best relation found was with the preceding spring pressure departures at Nome and at South Orkney, for which 22 years of record were available. The simple correlations in this case were: Temperature and Nome pressure, 0.438; temperature and South Orkney pressure, —0.579; pressures at Nome and South Orkney, 0.090. These gave a multiple correlation coefficient of 0.760 and a regression equation of $\Delta T_A = 0.12\Delta P_N - 0.47\Delta P_{S.O.}$ The curves of observed and calculated values, figure 1, give evidence of rather close agreement. They agree in sign 81 percent of the years, and there is complete agreement in sign whenever calculation forecasts a departure greater than 1°. Twice the calculated value misses the true value by as much as 2°, but the average error is 1.05°. The average observed departure is 1.55°. The two coldest seasons are correctly indicated by the two greatest calculated negative departures.

The second set of curves is for the winter temperatures in district 5, calculated from the preceding summer pressures at Honolulu and autumn pressures at Dutch Harbor. Simple correlations between temperatures and pressures are —0.599 and —0.411, respectively, and between the two pressures, 0.183. The multiple correlation coefficient is 0.641 and the equation is $\Delta T_W = -0.82\Delta P_H - 0.11\Delta P_{DH}$. The coefficient is smaller and the agreement obviously poorer than in autumn. Departures are of the same sign 55 percent of the time, and when the calculated departures are 1° or more, there is 75 percent agreement in sign. The two coldest winters are correctly indicated by the computed values, but there are four large errors, ranging from 3.9° to 5.7°. It will be noted that the calculated values average numerically less than the actual departures, and this is true in all the cases considered.

For spring we used pressure departures of the previous summer at Midway Island and at Lagos, Nigeria, for a period of 17 years. The simple correlation coefficients are: Temperature and Midway pressure, 0.679; temperature and Lagos pressure, —0.558; Midway and Lagos pressures, —0.285. The multiple coefficient is 0.778, and the equation is $\Delta T_{Sp} = 0.34\Delta P_M - 0.51\Delta P_L$. This is the highest coefficient obtained and the curves show a close agreement in most years. The departures are of the same sign in 15 of the 17 years, and in both cases of disagreement the calculated values are 0.2° or less and the observed values, 0.6° or less, so that in all years where either value is greater than 1° there is complete agreement in sign. The error of the computed values averages 1.0°; it is less than 1.0° in 10 cases, between 1° and 2° in 5 cases, and greater than 2° in 2 cases. The actual variation of the temperature as expressed by the average numerical value of the departures is 1.6°.

Finally, for summer we used pressure departures of the previous winter at Tokyo and the previous autumn at Rio de Janeiro, and with these stations a 40-year record was available. The simple correlation of temperature with Tokyo pressure is 0.413 and with Rio de Janeiro pressure 0.485, and that between the two pressures is 0.128. These resulted in a multiple correlation coefficient of 0.600 and a regression equation of $\Delta T_{Su} = 0.75\Delta P_T + 1.21\Delta P_R$. This equation gives values agreeing in sign in 29 of the 40 years, or 72 percent of the time. When the computed departure is 1° or more they agree 80 percent of the time and when the observed departure is 1° or more, 81 percent of the time. The variation of the observed values from normal is 1.5°; the error of the calculated values is 0.8°. The error is greater than 2° in 6 years, the greatest being 3.0°.

Returning to table 1, it will be noted that there are 20 multiple coefficients, ranging in value from 0.530 to 0.778. Thirteen of these have a value of 0.600 or more, and consequently have a forecasting value approximately equal to those for which the curves have been shown. Pressure in the north Pacific, as represented by Nome, Dutch Harbor, Markova, Honolulu, and Midway Island, occurs in 13 of the 20. The other pressure stations used are widely scattered, including points in Canada, British West Indies, Africa, Arabia, and Japan in the northern hemisphere, and including Rio de Janeiro, South Orkneys, and Batavia in the southern hemisphere. In the four cases for which computed values were obtained the average error was 1.24°, which is just two-thirds of the average observed departure of 1.86°. There is thus a 33 percent advantage in using the formulas; in summer the advantage is 46 percent.

We conclude that by the use of multiple correlation coefficients and regression equations, two largely independent pressure relationships can be combined to obtain fairly accurate indications of subsequent seasonal temperature departures in the Missouri and upper Mississippi Valleys on the average. These indications fail rather widely, however, in occasional individual years.
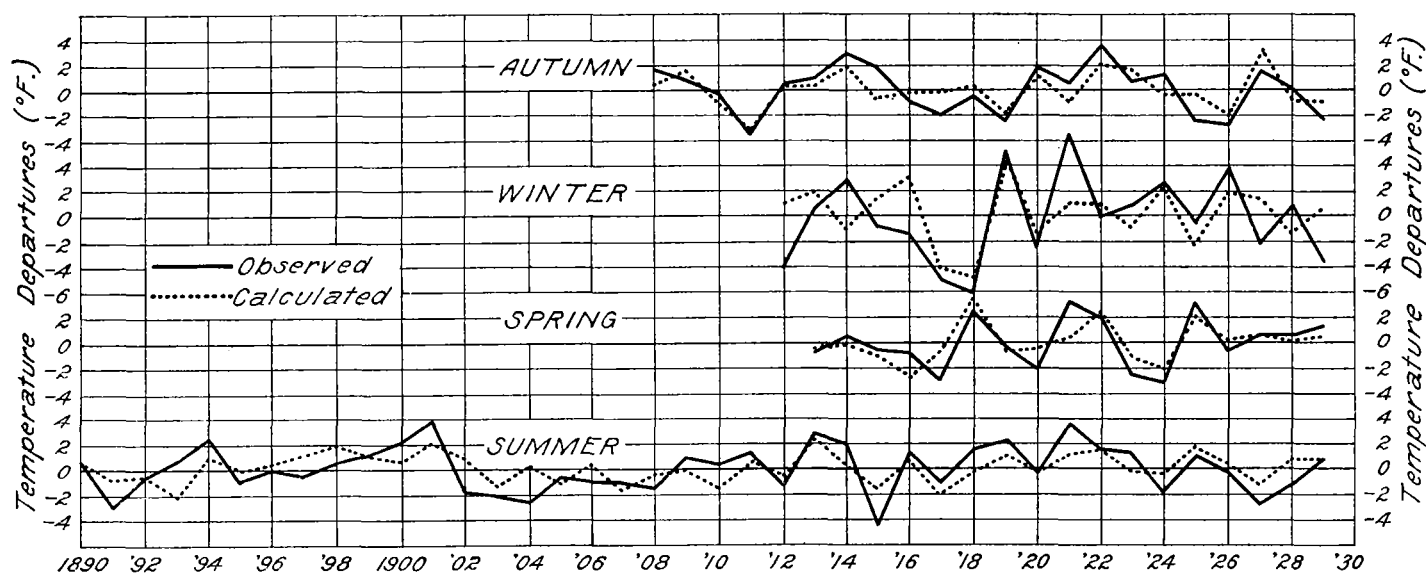
FIGURE 1.—Observed and calculated temperature departures in the Missouri and upper Mississippi Valleys.

TABLE 1.—*Multiple correlation coefficients. Temperatures are seasonal averages for 10 stations in the Missouri and upper Mississippi Valleys*

Temperature season	Pressure station and season	Period	Number of years	Multiple correlation coefficient
Winter	{Aden—summer / Batavia—spring}	1889–1929	41	0.582
Do	{Aden—summer / Bouzareah—spring}	1895–1929	35	.530
Do	{----do / Dutch Harbor—autumn}	1912–29	18	.566
Do	{Bouzareah—spring / Midway—summer}	1913–29	17	.595
Do	{Dutch Harbor—autumn / Honolulu—summer}	1912–29	18	.641
Spring	{Bouzareah—winter / Markova—summer}	1896–1920	25	.588
Do	{----do / Lagos—summer}	1896–1920	25	.587
Do	{Nome—summer / Nome—autumn}	1909–29	21	.647
Do	{----do / Markova—summer}	1909–20	12	.626
Do	{Lagos—summer / Nome—summer}	1909–29	21	.664
Do	{----do / Midway—summer}	1913–29	17	.689
Do	{Lagos—summer / Midway—summer}	1913–29	17	.778
Summer	{Rio de Janeiro—autumn / Bouzareah—autumn}	1895–1929	35	.569
Do	{Rio de Janeiro—autumn / Saint Vincent—spring}	1895–1929	35	.609
Do	{Rio de Janeiro—autumn / Rio de Janeiro—spring}	1890–1929	40	.600
Do	{Tokio—winter / Rio de Janeiro—autumn}	1890–1929	40	.600
Autumn	{Moose Factory—summer / Nome—spring}	1908–29	22	.636
Do	{Moose Factory—summer / Markova—winter}	1895–1919	25	.672
Do	{Moose Factory—summer / South Orkneys—spring}	1903–29	27	.630
Do	{----do / Nome—spring}	1908–29	22	.760

TABLE 2.—*Observed and calculated temperature departures in the Missouri and upper Mississippi Valleys*

Year	Autumn Calculated	Autumn Observed	Winter Calculated	Winter Observed	Spring Calculated	Spring Observed	Summer Calculated	Summer Observed
1890							0.4	0.5
1891							−.9	−3.0
1892							−.6	−.5
1893							−2.1	.6
1894							.9	2.3
1895							−.1	−1.0
1896							.1	−.1
1897							1.0	−.4
1898							1.8	.4
1899							1.0	1.1
1900							.5	2.0
1901							2.0	3.8
1902							.8	−1.8
1903							−1.4	−2.1
1904							.1	−2.6
1905							−1.0	−.7
1906							−.2	−1.0
1907							−1.5	−1.1
1908	0.5	1.6					−.4	−1.3
1909	1.4	.8					−.1	.9
1910	−1.0	−.2					−1.6	.2
1911	−3.3	−3.4					.5	1.1
1912	.4	.5	0.9	−4.0			−.6	−1.3
1913	.2	.9	1.8	.5	−0.7	−0.9	2.2	2.7
1914	1.8	2.9	−1.0	2.9	−.2	.4	.1	1.9
1915	−.6	1.8	1.3	−.8	−1.1	−.4	−1.5	−4.5
1916	−.2	−.9	.3	−1.4	−2.6	−.8	−.5	1.2
1917	−.1	−1.9	−4.0	−5.0	−.7	−2.8	−2.2	−1.1
1918	.2	−.6	−4.8	−6.2	3.5	2.6	−.4	1.4
1919	−1.9	−2.3	4.3	5.2	−.7	−.2	.8	2.1
1920	1.0	1.8	−1.3	−2.5	−.6	−2.1	−.3	−.3
1921	−.9	.3	.8	6.5	.3	3.1	.9	3.3
1922	2.0	3.4	.8	−.1	2.4	2.0	1.2	1.2
1923	1.4	.7	−.9	−.8	−1.2	−2.5	−.2	1.1
1924	−.3	1.1	2.2	2.6	−2.1	−3.2	−.3	−1.9
1925	−.3	−2.5	−2.4	−.7	1.9	3.0	1.7	.9
1926	−2.0	−2.8	1.7	3.7	.1	−.6	.1	−.1
1927	3.0	1.4	1.3	2.2	.7	.7	−1.3	−2.8
1928	−.9	0	−1.6	.8	.2	.4	.5	−1.4
1929	−.8	−2.3	.7	−3.7	.4	1.1	.5	.4